



superior performance.  
powerful technology.

# SuperPower 2G HTS Wire for Demanding Electric Power Applications

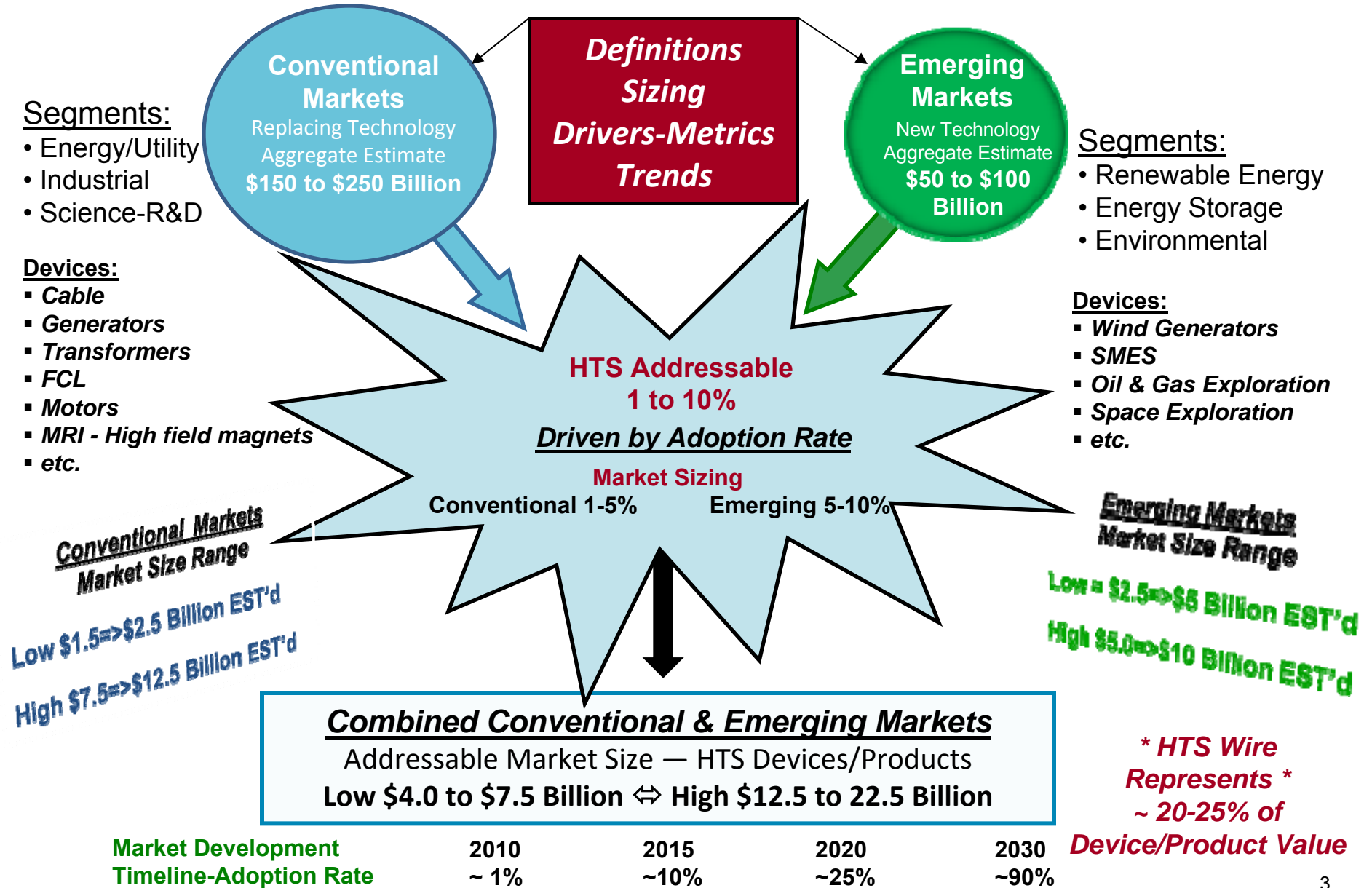
Traute F. Lehner  
Sr. Director of Marketing & Govt Affairs, SuperPower Inc.

*The 10<sup>th</sup> EPRI Superconductivity Conference  
Florida State University – The Center for Advanced Power Systems  
Tallahassee, Florida  
October 11-13, 2011*

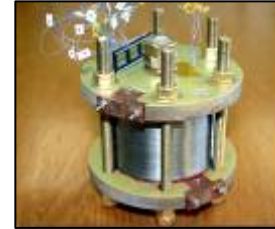
# Focus of discussion

- HTS Market
  - Market sizing
  - Adoption factors
- Critical Success Factors for market adoption
  - Price
  - Technology
  - Demonstrations
  - Manufacturing

# HTS market sizing model & analysis



# HTS device portfolio - What are the winning devices?



Energy	Defense	Transportation	Industrial	Medical	Science/ Research
<ul style="list-style-type: none"> <li>• <b>Cable (ac, dc)</b></li> <li>• <b>FCL</b></li> <li>• <b>Generators</b> <ul style="list-style-type: none"> <li>– Wind</li> <li>– Utility</li> <li>– Hydro</li> </ul> </li> <li>• <b>Transformers, incl. FCL</b></li> <li>• <b>Storage</b> <ul style="list-style-type: none"> <li>– <b>SMES</b></li> <li>– Flywheels (Bearings)</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Motors, propulsion</b></li> <li>• <b>Cable, degaussing</b></li> <li>• Directed energy weapons</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Maglev</b></li> <li>• Motors, Marine propulsion</li> <li>• Rail engines</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Induction heaters</b></li> <li>• <b>Motors, industrial</b></li> <li>• <b>Generators</b></li> <li>• Magnetic separation</li> <li>• Bearings</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Current leads</b></li> <li>• <b>MRI</b></li> <li>• NMR</li> </ul>	<ul style="list-style-type: none"> <li>• <b>HF magnets</b></li> <li>• <b>Space exploration</b></li> <li>• SQUIDS</li> <li>• High energy physics</li> <li>• Electronics</li> <li>• Cell tower base station filters</li> </ul>



**Key:**

- **Near-Term addressable by 2G HTS - 1-5 years**
- **Government interest/funding - Mid-Term 3-7 years**
- **Longer term/other - 5-10 years**

# SuperPower's assessment of HTS wire market

- Today - **Cable** is the only market that could consume 100% of available capacity
  - High volume required, Limited performance attributes required, Price sensitive
  - Significant capital investment required to meet volume
- **AP wire** provides the greatest degree of Price/Performance attributes that create defensible position
  - Motor, Generators, SMES, Transformer, High Field Magnets, etc.
  - Continuous technology advancement to further improve barrier of defense
  - Price to customers can be achieved while profit level can be more easily maintained
  - For the near future, the wire supply will be well matched to the demand and will allow for a reasonable ROI
- **FCL Wire** – has favorable performance, price, and volume requirements, but market timing to consume 100% of capacity is questionable
- **SuperPower approach: focus on a price/performance product mix that provides:**
  - Potential contribution margins to provide pathway to profitability for all
  - Volume sufficient to load factory at capacity
  - Sales to multiple markets / applications until a clear commercial product is identified and developed

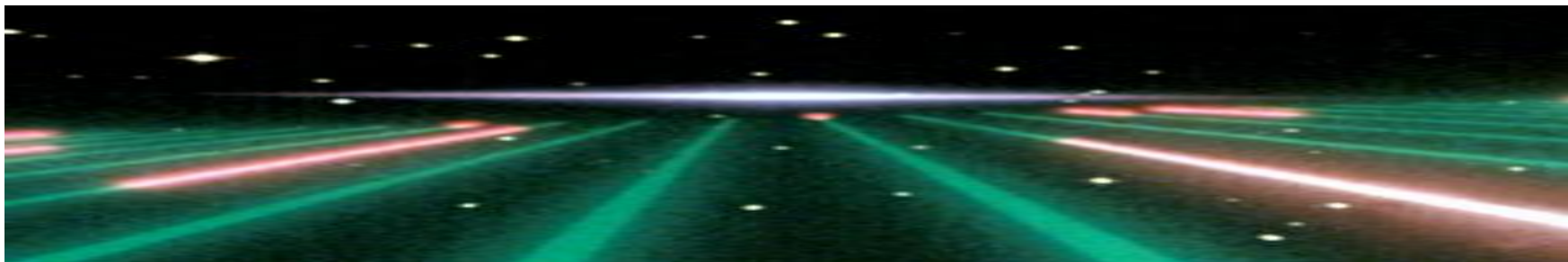
# Accelerate the HTS adoption rate toward commercialization

## Technology advancement

- Wire
  - Achieve competitive price
  - Increase throughput / supply
  - Meet performance parameters
- Providing a robust product portfolio
  - Market / device-driven
- Continuing device demonstrations
  - Government funding
  - Strategic partners

## Reduced business risk

- Price must be competitive with alternative technologies
- Meet or exceed customer expectations
  - Supply
  - Quality
  - Performance
- Provide superior customer service and support

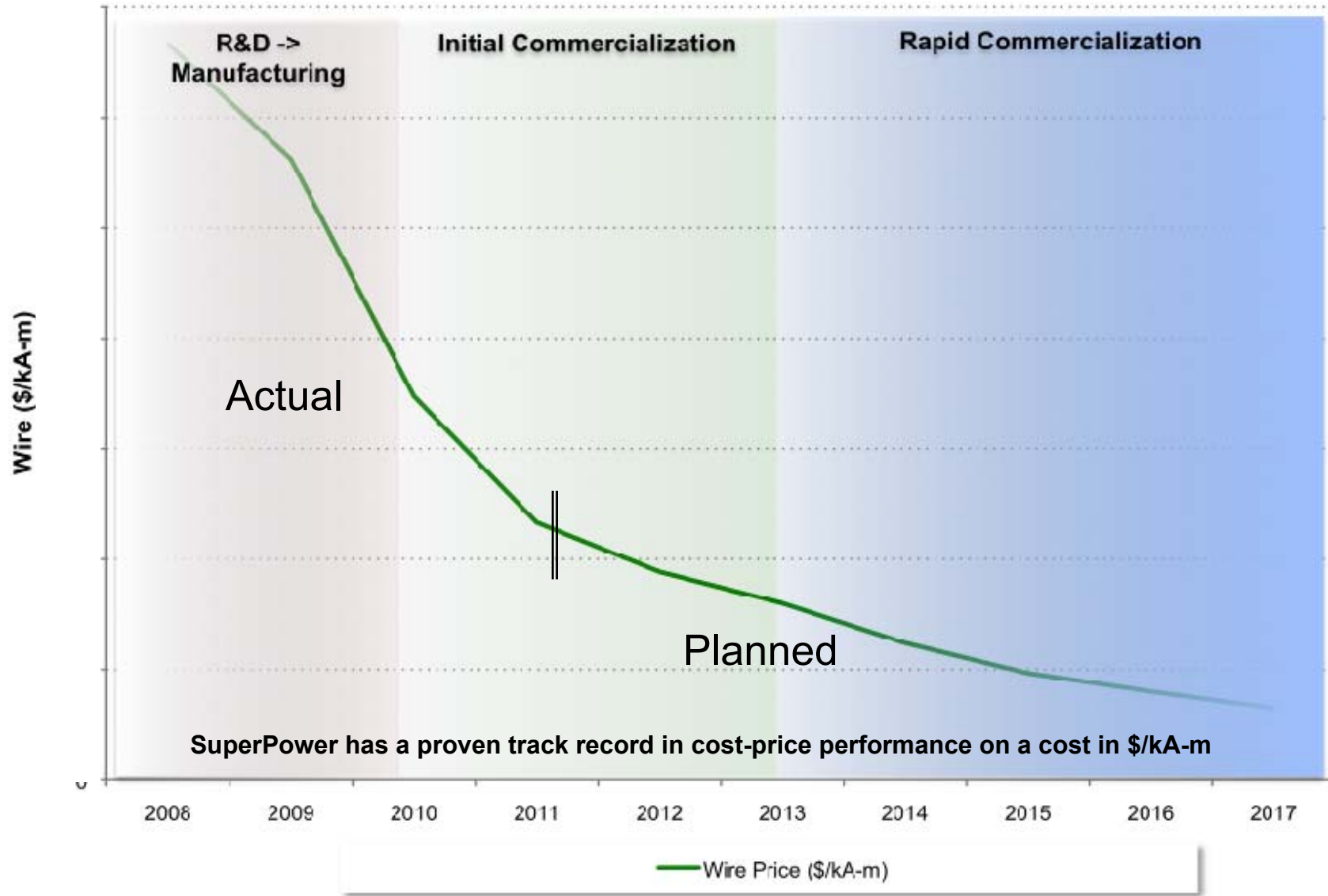




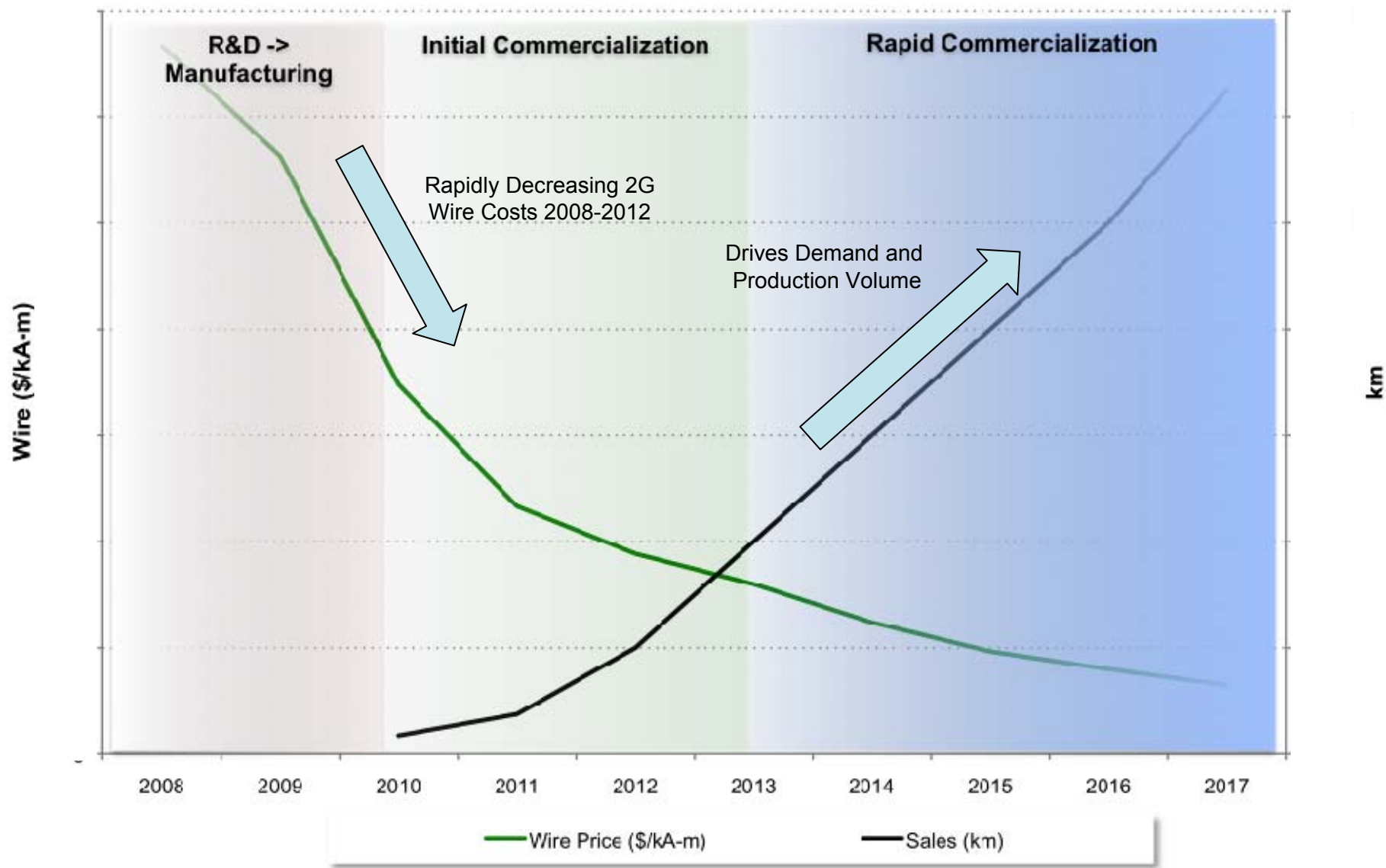
superior performance.  
powerful technology.

*Critical Market Adoption Success Factor:*  
Price

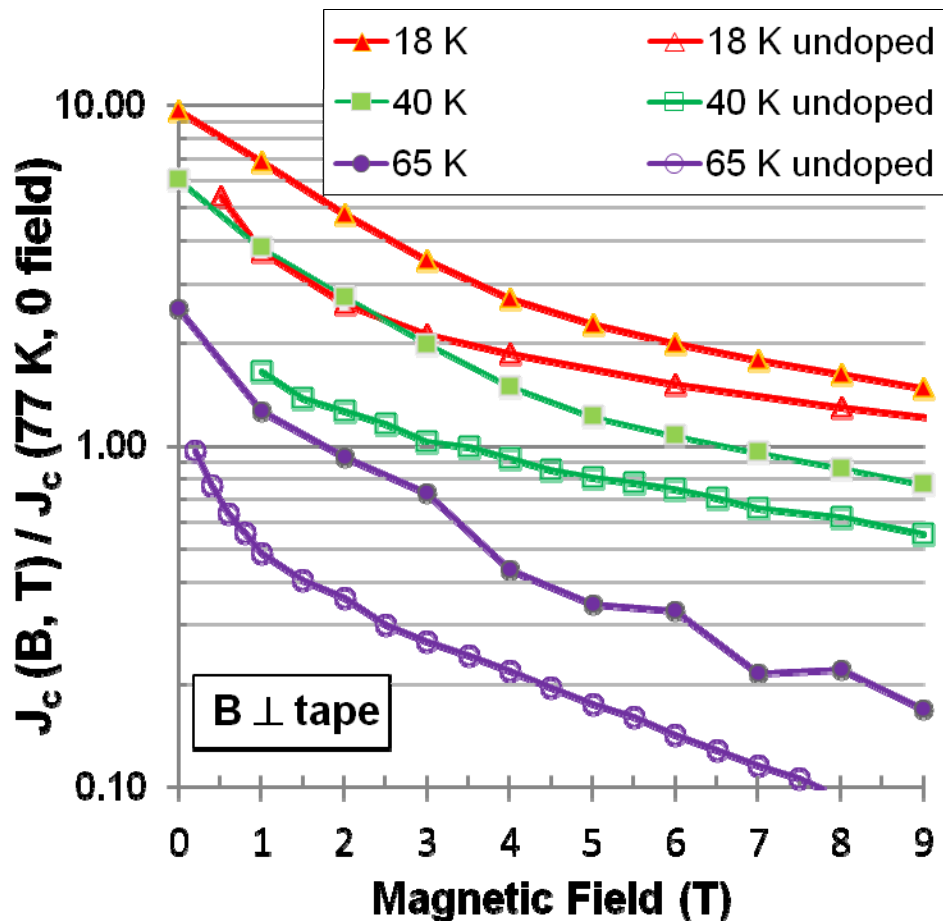
# Driving demand



# Driving demand



# In-field performance is greatly improved



Lift Factor of 77 K, zero field $I_c$	65 K 3 T	40 K 3 T	18 K 3 T
Undoped wire	0.27	1.02	2.13
Zr-doped wire	0.73	1.99	3.50
Lift factor of Zr-doped wire is higher by	2.7	1.9	1.6

At 40K and 3T, the quantity of wire required for device is **reduced by ½**, greatly improving the economics of the device.

## SuperPower driving Price / Performance down on two fronts: Improving manufacturing process and in-field performance

Time	Performance at 77 K, zero field	Lift Factor at device operating condition	Performance at device operating condition	Wire price (\$/m)	Wire price (\$/kA-m) at device operating condition
Now	100-130 A	2	260 A	45	\$175
2 years	160 A	4	640 A	35	\$ 55
4 years	200 A	6	1200 A	35	\$ 30

*Improving wire performance is key to the success of our approach*



superior performance.  
powerful technology.

*Critical Market Adoption Success Factor:*  
Technology Focus - Performance  
Improvement Requirements

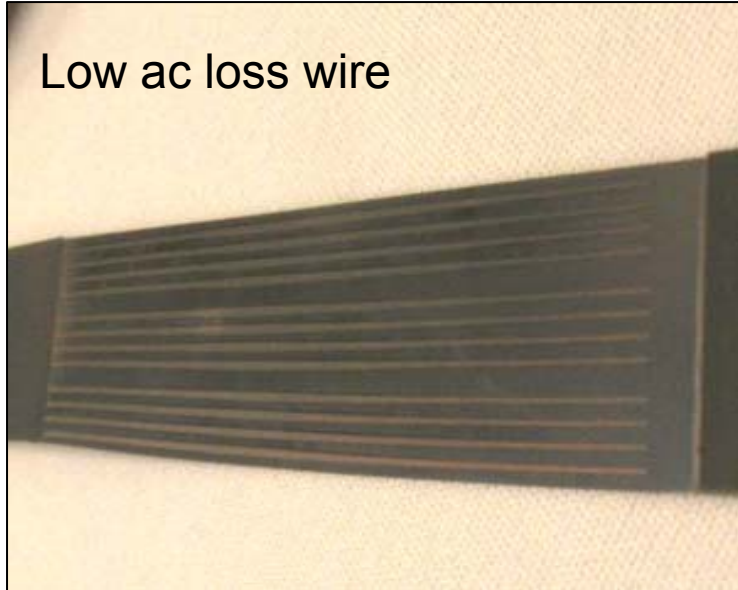
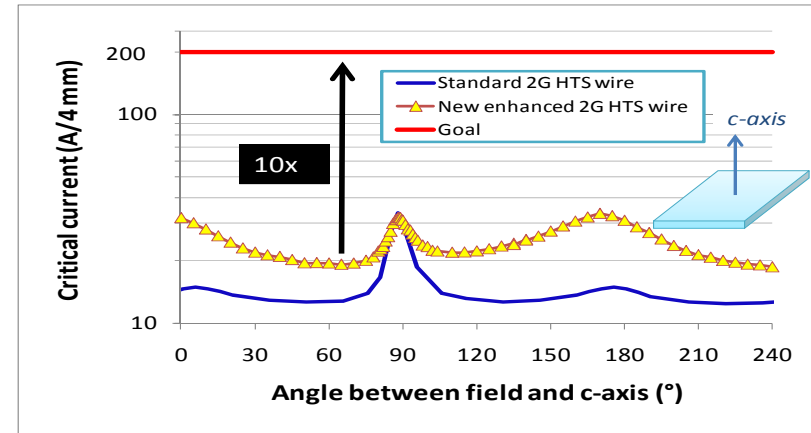
# Summary of technology development goals

Achieve higher amperage

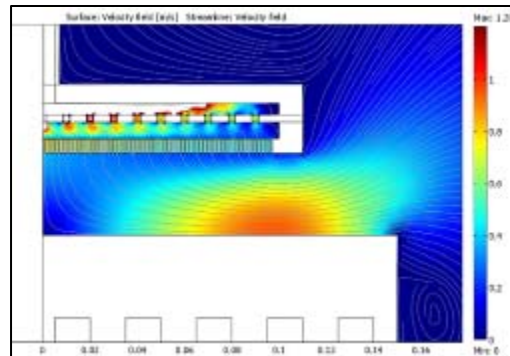
	Today	2 yrs	5 yrs
Ic at 77 K *	100-130 A	200 A	300 A

\* 4 mm width

Improved in-field performance



Increased production and reduced cost



# Aggressive R&D Goals Established

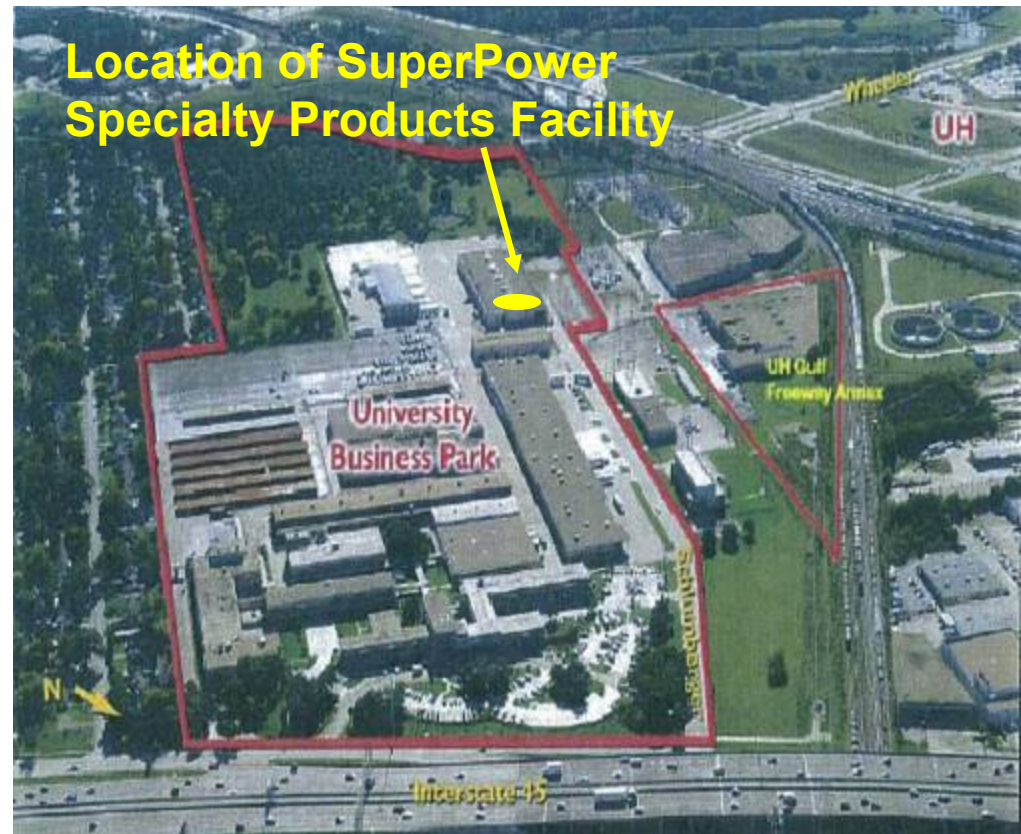
- Plenty of opportunities for 10x improvement in production wire performance at low temperatures & high fields → 10x lower cost/performance
- 300 A/ 4mm target for production wires: 3x today's capability
- 3x additional improvement lift factor in high magnetic fields at low and intermediate temperatures by enhanced pinning schemes
- Scalable processes being developed for fully striated multi-filamentary wires in long lengths for low ac losses; ac loss reduction goal 5x (near term) to 30x
- 3x improvement in MOCVD process efficiency targeted using novel equipment engineering → 3x lower cost + 3x higher throughput
- Continued R&D for novel in-line process control and quality control for high yield manufacturing of long piece-length conductors

*Superior product configurations available now....*

*Expect **Extraordinary and Universal product** in the next five years!*

# Planning ahead: Specialty Products Facility in Houston

- New SuperPower facility at UH Energy Research Park – opening Jan 2012
- 5<sup>th</sup> MOCVD system procured by UH to be installed at SPF
- Advance R&D at UH to scale up to Manufacturing in Schenectady
- Supplement Schenectady production demand requirements

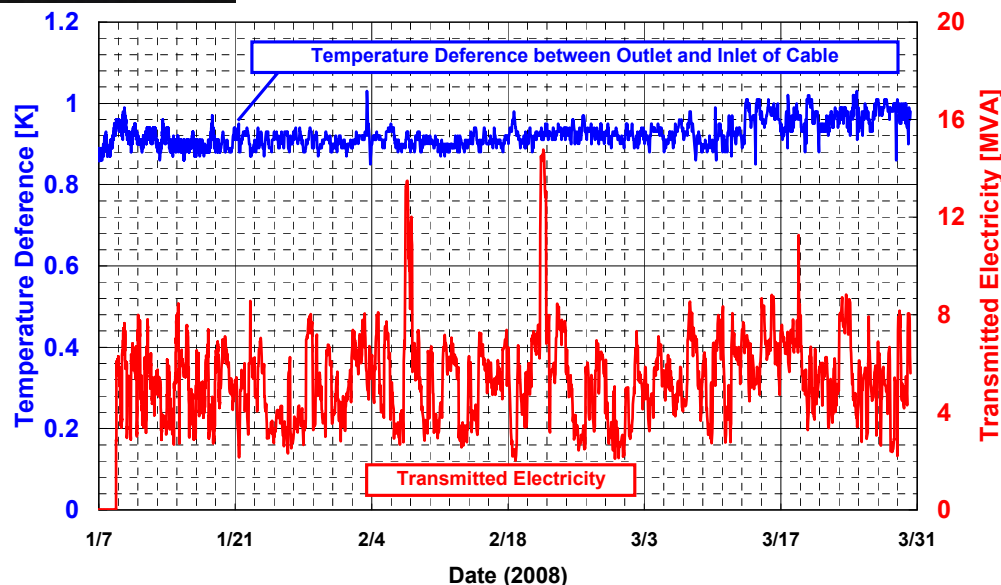
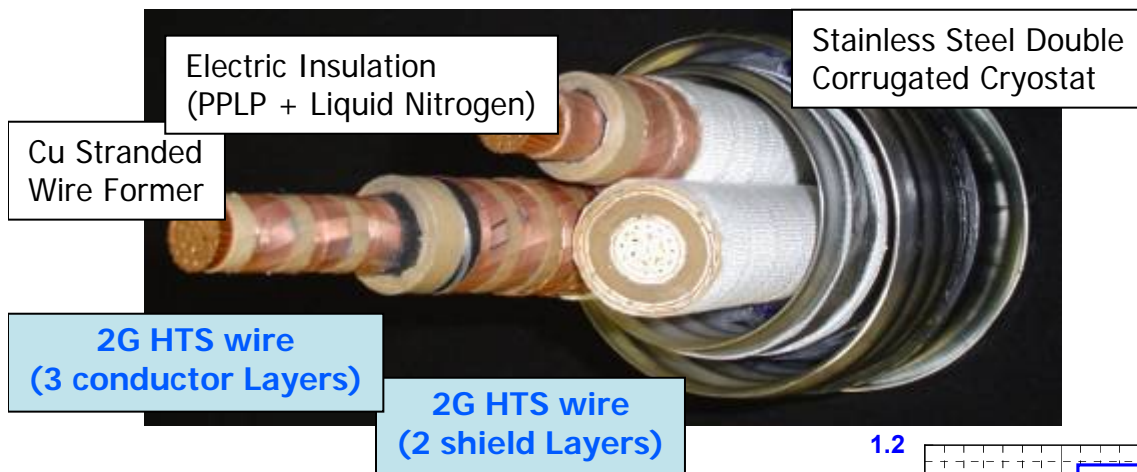




superior performance.  
powerful technology.

*Critical Market Adoption Success Factor:*  
Application Team Focus - Demonstration  
Projects with Partners

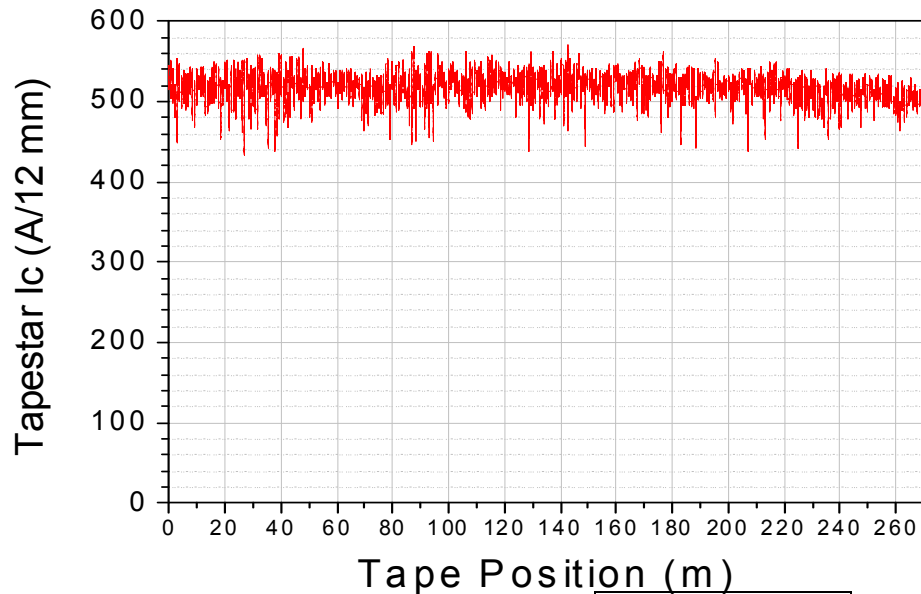
# Demonstration of the world's first device with coated conductors in a live power grid



*350 m cable made with 30m of 2G HTS energized in the grid  
Jan. 2008 - supplied power to 25,000 households in Albany, NY*

# Stringent requirements for FCL being met

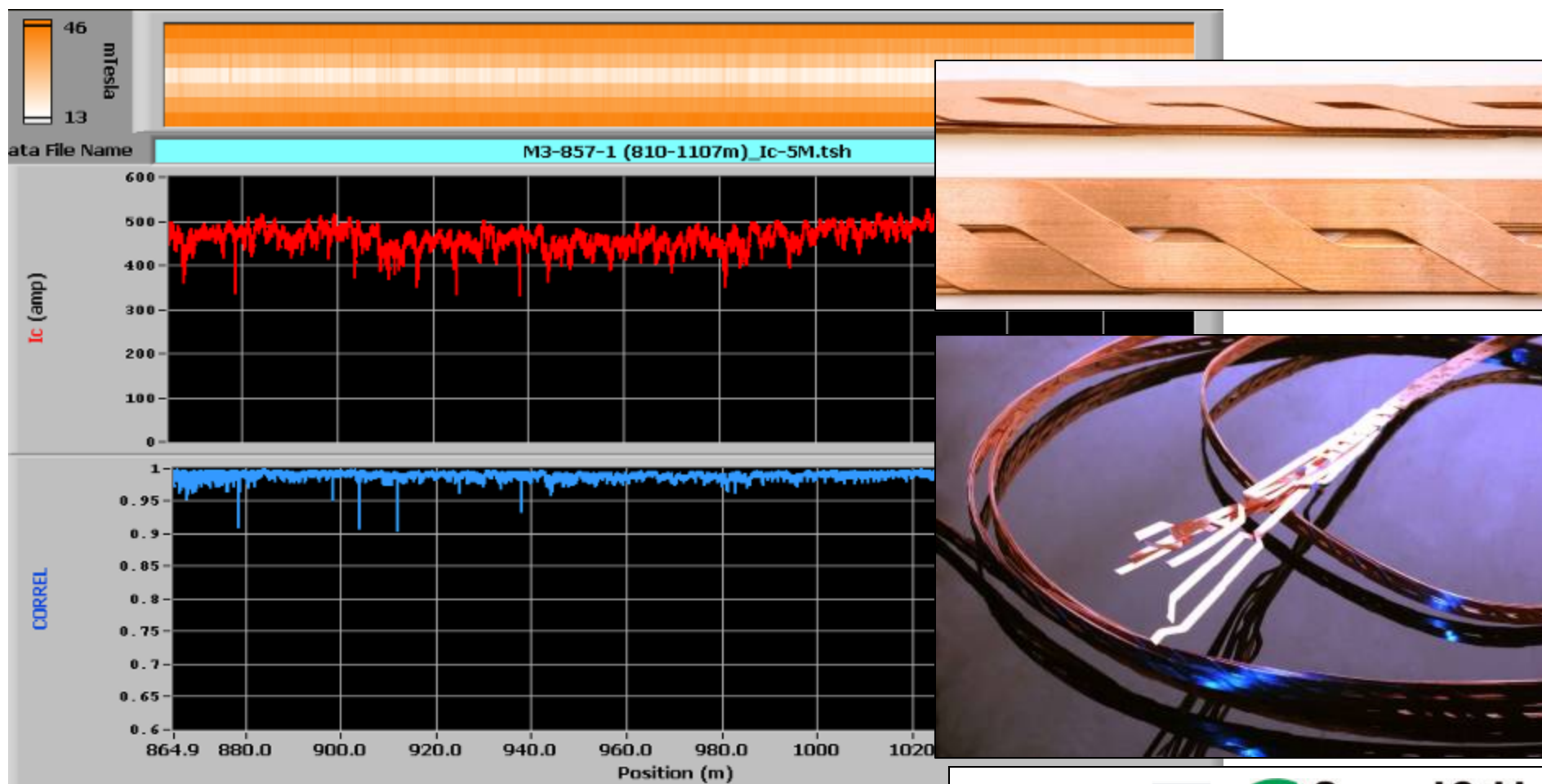
High critical currents over long lengths with a **tight  $I_c$  bandwidth** (spec for both minimum and maximum  $I_c$ ) to ensure uniform quench



Operating current: 2.7kA (565A continuous)  
Prospective current: 63 kA peak, 25 kA rms  
Limited current: <21 kA peak, <7 kA rms

ROEBEL cables made with 2,000 m of coated conductor with uniform  $I_c$  and excellent 2D  $I_c$  uniformity

$I_c = 341 \text{ A}/12 \text{ mm}$ , single piece length = 297 m **Correlation coefficient > 0.9**



# Multiple coil applications using AP wire



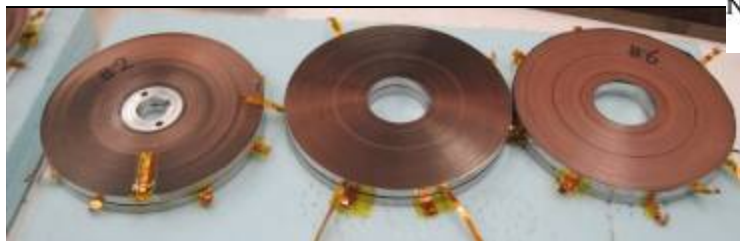
3.6 T gantry magnet for **Particle Beam Therapy**. Four racetrack coils and 14 bent coils. 2,500 m with min  $I_c$  of 115 A/4 mm.



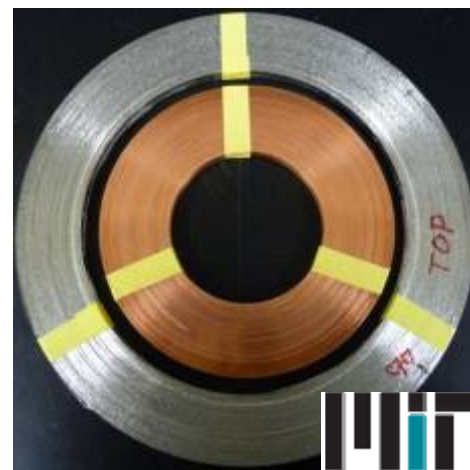
**Linear Induction Motor** using 3 mm wide conductor to reduce ac losses



**20+T HTS solenoid for muon collider**

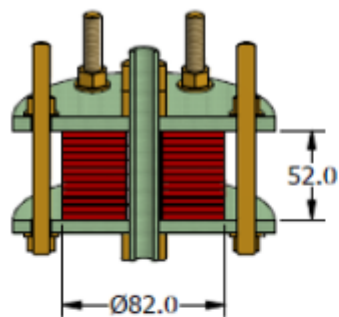


Race track coils for **generator**

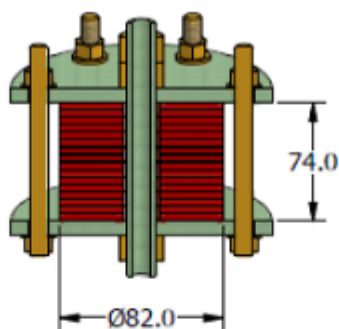


**1.3 GHz NMR Magnet**  
8.34 T contribution from coated conductor coil

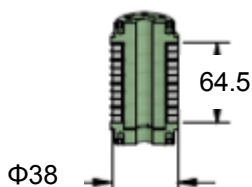
# Ultra high-field magnets demonstrated at 4.2 K with AP wire



SuperPower I.  
 $B_{max} = 26.8 \text{ T}$   
 $\Delta B = 7.8 \text{ T}$

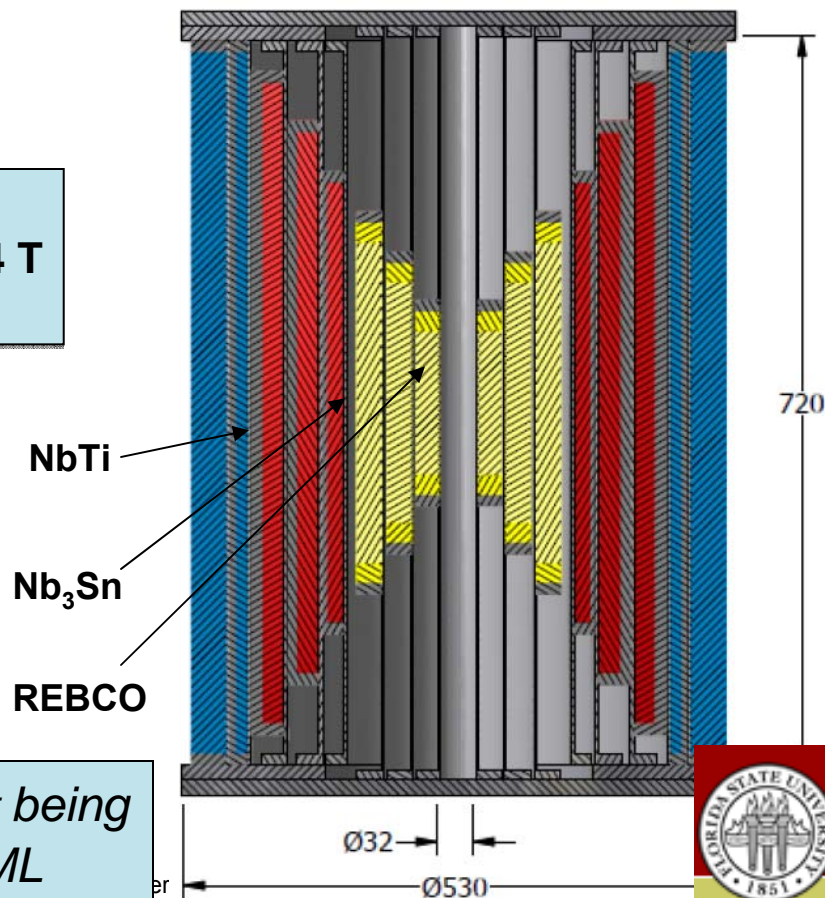
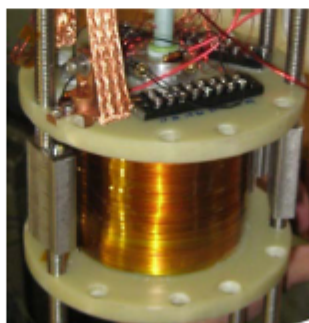
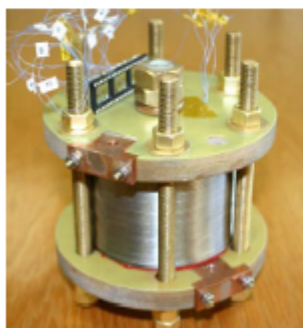


SuperPower II.  
 $B_{max} = 27 \text{ T}$   
 $\Delta B = 7 \text{ T}$



NHMFL II.  
 $B_{max} = 35.4 \text{ T}$   
 $\Delta B = 4.2 \text{ T}$

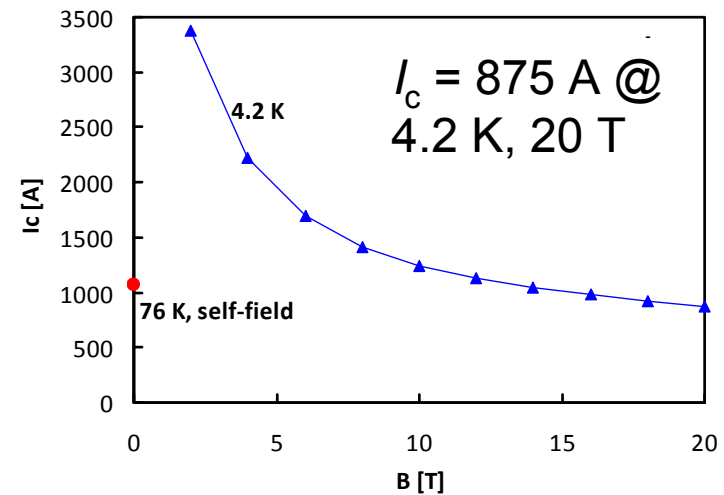
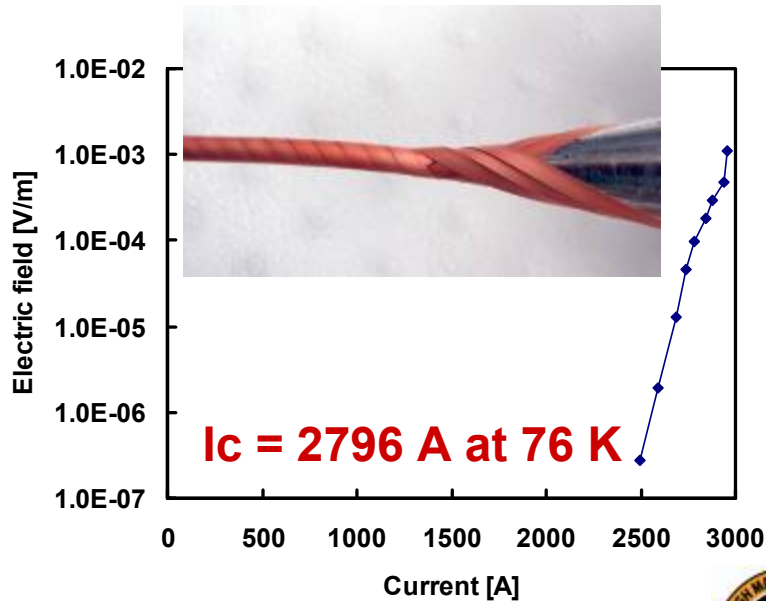
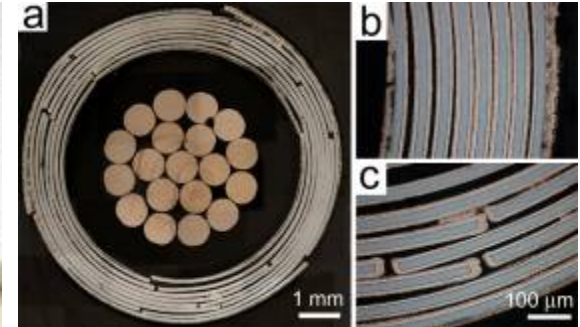
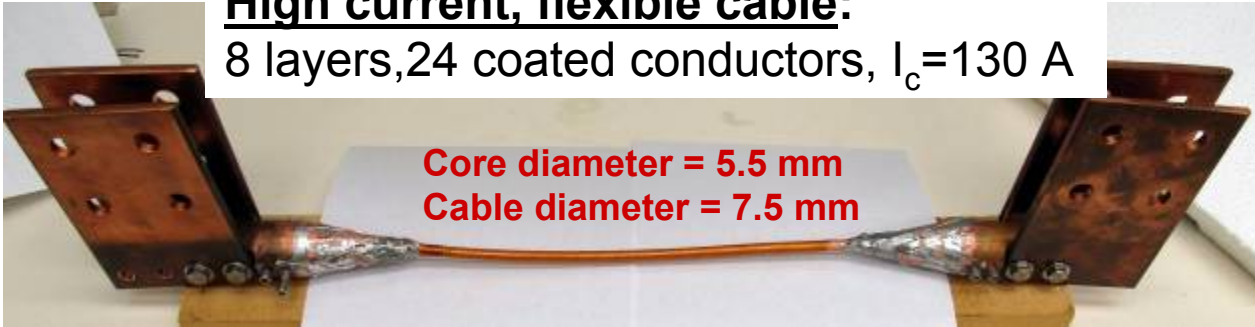
- $J_e \sim 300 \text{ A/mm}^2$
- Stress levels 300 – 400 MPa



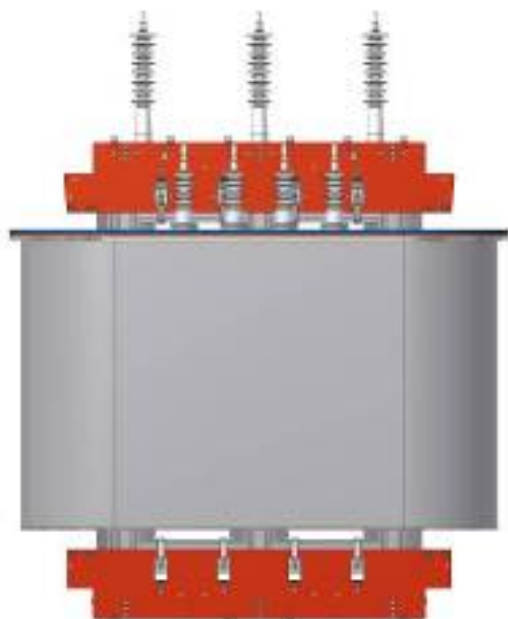
*32 T, large bore all superconducting magnet being constructed with coated conductors at NHFML*

# New applications possible with excellent mechanical properties & in-field performance

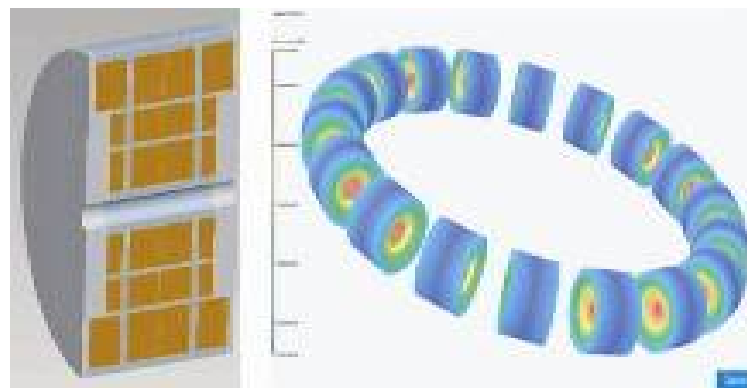
**High current, flexible cable:**  
8 layers, 24 coated conductors,  $I_c = 130$  A



# Current SuperPower demonstration projects



DOE Smart Grid  
Demonstration Program -  
Superconducting  
FCL Transformer  
Waukesha – SuperPower –  
Oak Ridge National Laboratory



ARPA-E GRIDS Program -  
SMES Project

## **New Program – October 2011!**

ARPA-E REACT Program – Low-  
cost wire for HTS Wind Turbine  
Generators

SuperPower – UH –  
NREL –  
TECO Westinghouse





superior performance.

powerful technology.

*Critical Market Adoption Success Factor:*  
Manufacturing Focus - Scale Up to Meet  
Market Demand

**PHILIPS**

SuperPower Inc. is a subsidiary of Royal Philips Electronics N.V.

# Expanding manufacturing operations to meet customer demand

## ***Increasing annual capacity***

## ***Improving manufacturing efficiency & effectiveness:***

Yield

Throughput

Quality assurance

On-time delivery

Cost improvement

## ***Product engineering/application support***

Quality certification

New product

Customer technical support

Coil design/engineering and fabrication

# Equipment Engineering advances for testing kilometer lengths of coated conductor

- LTS wire is tested only at two ends
- Coated conductor is tested for  $I_c$  and n-values **100% over entire length**



**2003:**  $I_c$ , n-value  
1 m intervals



**2006:**  $I_c$ , n-value, thickness, width  
measurement in 5 m intervals

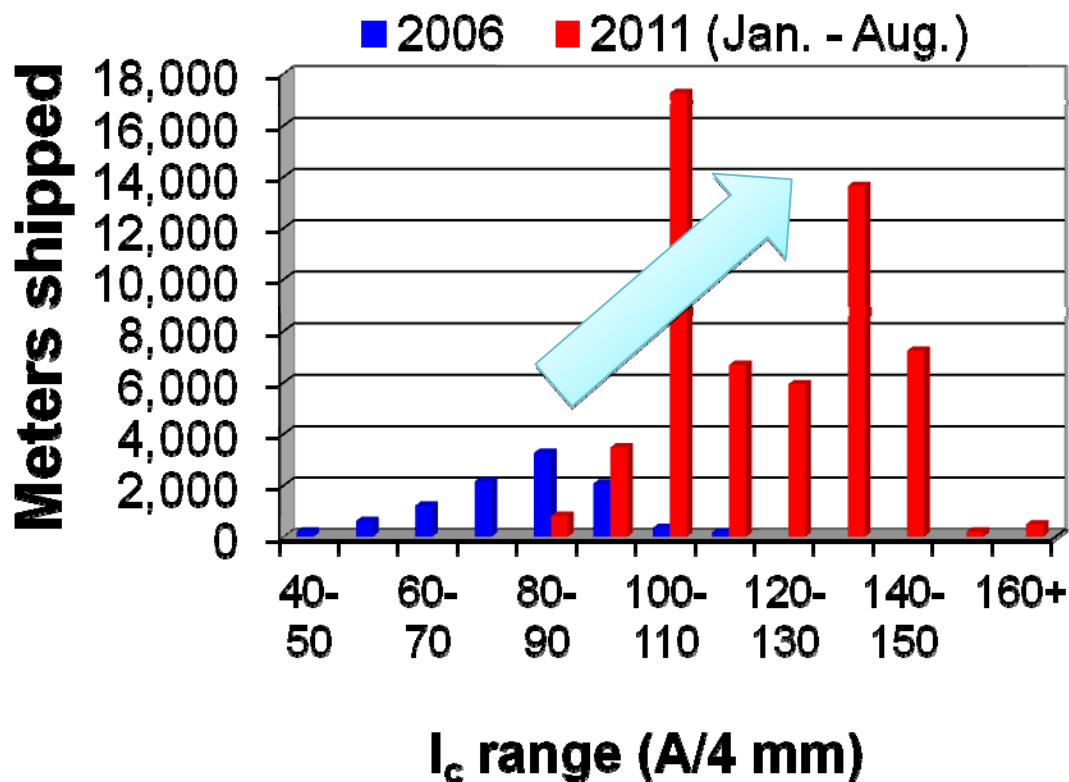


**2011:**  $I_c$ , n-value, thickness, width  
measurement in 10 m intervals

# SuperPower Wire: Competitive Assessment

	SuperPower	Others	Advantage for		
			Coil	FCL	Cable
Performance at 77 K, zero field (4 mm wide)	100 to 160 A	100 A	SP	SP	SP
'Lift Factor' in magnetic field (at 30 K, 2 T)	2.6	1.2	SP	---	---
ac losses	Medium	High	SP	SP	SP
Engineering current density	2x	1x	SP	---	---
Strength	700 MPa	250 MPa	SP	---	---
Resistivity	High	Medium	---	SP	---
"Stiffness"	Medium	High	---	---	Others
Production volume	~ 300 km/yr	>> 300 km/yr ?	---	---	Others

# Large increases in coated conductor shipments and performance in last 5 years



Metric	2006	2011
Average $I_c$ (A/4 mm)	80	122
$I_c$ range (A/4 mm)	40 – 118	80 - 165

*50% increase in average  $I_c$ , 100% increase in minimum  $I_c$  and 40% increase in maximum  $I_c$  achieved in 5 years of pilot manufacturing*

# Significant advances in manufacturing of coated conductors in the last five years

- Long lengths routinely manufactured
  - 1,000 m demonstrated with minimum  $I_c$  of  $\sim 300$  A/cm
  - 100 – 300 m typical shipped lengths
- High critical currents in production wires
  - Critical currents of wires shipped in 2011 range from 80 to 165 A/4 mm with an average of 122 A/4mm
- Excellent in-field performance in high fields at intermediate and low temperatures
  - 800 A/cm ( $J_e = 800$  A/mm<sup>2</sup>) at 4.2 K, 10 T, field perpendicular to wire
  - 600 A/cm at 40 K, 3 T, field perpendicular to wire
- Customized to meet unique requirements of multiple applications
  - Excellent 2D uniformity of critical current across width for ROEBEL cables
  - Tight band of critical current for FCL
  - Several prototypes of cables, FCL, coils demonstrated
- Superior mechanical properties
  - Yield strength  $> 700$  MPa with superalloy-based coated conductors

## Looking ahead: SuperPower's primary areas of focus

- Scaling up manufacturing operations to ensure supply
- Advancing the technology
- Meeting the price / performance challenge
- Providing excellent customer support
- Working closely with all stakeholders
- Collaborating to ensure success
- Participating in device demonstrations

**Thank you for your interest!**